Can we predict the magnetic loss of a nanocrystalline core from LCR-meter characterization?

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Nanocrystalline cores are key for high-frequency applications due to their low hysteresis losses, but predicting dynamic losses remains challenging. This study explores using LCR-meter-based permeability spectroscopy (µS) to characterize these materials and predict losses via fractional derivative models. The method offers a rapid, industry-friendly alternative to complex hysteresis setups.

Keywords: Cole-cole model, fractional derivative, power loss

1. Introduction

Nanocrystalline ferromagnetic materials are widely used in high-frequency applications such as transformers, inductors, and electric vehicle components due to their superior soft magnetic properties, including low core losses and high permeability [1]. Unlike traditional electrical steels, these materials exhibit minimal static hysteresis losses, making them ideal for energy-efficient designs. However, accurately predicting their dynamic magnetic losses, especially under high-frequency conditions, remains a challenge. This study explores the feasibility of using permeability spectroscopy (µS) via an LCR-meter to characterize nanocrystalline cores and predict their magnetic losses [2]. µS offers a rapid method to assess dynamic behavior by analyzing impedance variations during frequency sweeps. We investigate the correlation between µS-derived parameters and the frequency-dependent hysteresis cycles measured under controlled conditions. The goal is to establish a reliable, industry-friendly method for loss prediction without requiring complex experimental setups.

2. Experimental setup

LCR-Meter Characterization: The experimental setup for µS consists of an LCR-meter. The complex permeability $\mu=\mu'+j\mu''$ is derived from impedance measurement. Frequency sweeps (e.g., 10^2–10^7 Hz) are performed under sinusoidal excitation (2–100 mA) to capture dynamic permeability variations.
Hysteresis Cycle Measurement: A dedicated setup measures quasi-static and dynamic hysteresis cycles $B_a(H_{surf})$ under sinusoidal flux density conditions (3 Hz–20 kHz). The quasi-static loops (3 Hz) serve as a baseline, while high-frequency cycles reveal loss mechanisms like eddy currents and domain wall dynamics.

3. µS and Dynamic permeability

IS reveals distinct relaxation frequencies linked to magnetization mechanisms (e.g., domain wall motion, rotation). The real part of the permeability (µ′) decreases with frequency, while the imaginary part (µ″) peaks at relaxation points (Fig. 1 left).

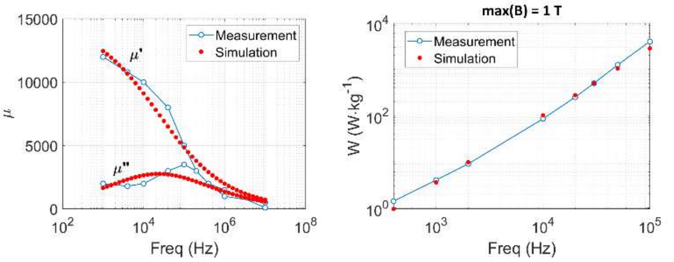

Figure 1: Comparisons simulation/measurement µ'(*f*), µ''(*f*) (left). Comparison simulation/measurement for the magnetic losses (right).

A Cole-Cole model fits the µS data, with parameters τ (relaxation time) and n (fractional order, [3]) extracted for loss prediction. A fractional derivative model simulates dynamic losses using µS-derived parameters. Comparisons with measured losses show strong agreement (Fig. 1 right). In nanocrystalline core excess losses dominate (>75% at 20 kHz), attributed to nanocrystalline microstructure and Classical eddy losses are minimal due to the ribbon's thinness.

4. Discussions and conclusions

µS requires only an LCR-meter, avoiding complex hysteresis characterization setups. The fractional order n and ρ are consistent across methods, enabling transferability from µS to simulations. Domain wall dynamics in nanocrystalline materials necessitate low n values (viscoelastic balance), differing from conventional steels. LCR-meter-based µS is a promising tool for predicting magnetic losses in nanocrystalline cores.

References

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